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Review paper

Global Climate Change Impacts on Pacific Islands Terrestrial Biodiversity: a review

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Abstract

The islands of the Pacific region hold three of the 35 global biodiversity hotspots with large numbers of endemic species. Global climate change will exacerbate the challenges faced by the biodiversity of this region. In this review, we identify trends in characteristics for 305 terrestrial species threatened by climate change and severe weather according to the International Union for Conservation of Nature and Natural Resources (IUCN). We then review the literature on observed and potential impacts of climate change on terrestrial biodiversity, focusing on the species' characteristics that were identified. High-elevation ecosystems such as cloud montane forests are projected to disappear entirely by the year 2100, with corresponding global losses of their endemic biodiversity. Sea level rise threatens restricted range species on small low-lying atolls. Shifts in distribution may be possible for generalist species, but range shifts will be difficult for species with small distributions, specialized habitat requirements, slow dispersal rates, and species at high elevations. Accurate assessments of climate change impacts on biodiversity of the region are difficult because of confusion about nomenclature, the many species unknown to science, the lack of baseline data on species' ecology and distributions, and lack of fine resolution elevation data for very small islands. Furthermore, synergistic interactions of climate change with other threats like habitat loss and invasive species have not been comprehensively assessed. Addressing these knowledge gaps will be difficult for Pacific island nations due to limited financial resources and expertise.

Keywords: Biodiversity Conservation, Climate Change, Sea Level Rise, South Pacific Islands, Endemic Species, Extinction Risk

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Introduction

There is now ample evidence that climate change is occurring and is impacting global biodiversity [1]. An undeniable consequence of climate change is sea level rise [2]. The impacts of climate change and sea level rise will be felt acutely by the biodiversity on small, low-lying islands surrounded by open ocean [3, 4]. The Pacific region is one such area, comprising the islands of Melanesia, Polynesia and Micronesia [5] (Fig. 1). The islands have complex and diverse geological histories, which have led to the evolution of a unique biota [6]. They are scattered over a large area of approximately 40 million km^2 of ocean with sizeable distances between islands and island groups [5]. Three of the 35 global biodiversity hotspots (East Melanesian Islands, New Caledonia and Polynesia-Micronesia) are found here, with numerous endemic species [7, 8], many of which are listed on the IUCN Red List of threatened species [9] (Appendix 1).

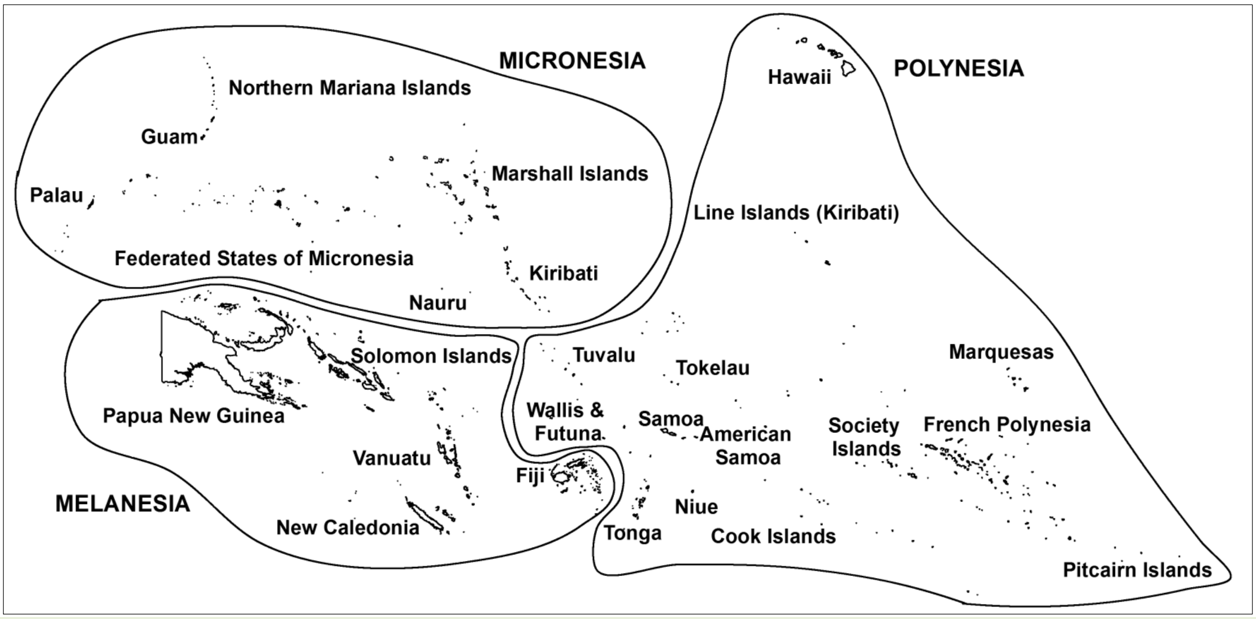

Fig. 1. Map showing the islands in Melanesia, Micronesia and Polynesia.

Islands can be categorized into four groups (volcanic, low limestone, raised limestone, and continental islands) based on the elevation and the types of rocks that form the island, which in turn influence the ecology of the island and its biodiversity [6, 10]. The region is experiencing rapid economic growth and a rising human population, which place growing demands on natural resources. Agricultural expansion, overexploitation of natural resources, deforestation, pollution, coastal development, and invasive species are causing fragmentation and destruction of habitats, which in turn pose serious threats to the many rare and endemic species found on these islands [11-14]. The addition of climate change and sea level rise to these threats exacerbates the pressures and challenges that will be faced by the biodiversity of this region, especially in light of the *rate* of climate change forecast by the latest IPCC report [1]. However, the impacts will be variable for the different countries in the region and also dependent on the size of individual islands. For example, tropical cyclone activity in this region is highly dependent on El Niño–Southern Oscillation (ENSO) cycles. Often an increase in cyclone activity in one region is countered by low activity in another [15]. Furthermore, changes in sea level and tidal ranges are also projected to be variable for the different countries in the region [16] (Appendix 2), and the islands' topographical differences will cause varying susceptibility to sea level rise [17]. Consequently, the impacts on biodiversity in the different countries will also vary.

"Organisms on continents can gradually change their area of distribution in response to changing environmental conditions……….the fate of island organisms is played out within the small confines of the island they inhabit – there is no adjacent territory to which they can retreat if the island environment becomes less congenial" [18].

Islands, particularly small, low-lying reef islands, are spatially restricted environments [19]. Unlike species on continents, species on small islands have limited opportunities to adapt to changing environmental conditions by altering their distribution, given the limited area of small islands [18]. Nevertheless, the organisms that live on islands must be able to survive periodic variations in their environment. Surviving changes in environmental conditions may not be as simple for island species as for continental ones due to a variety of characteristics as outlined below. Research has shown that island biota are generally at a higher risk of extinction and that island extinctions are two to three orders of magnitude higher than continental rates for birds and mammals [20-23]. Extinction risk is strongly associated with limited geographic distribution at a variety of scales. Thus, risk is higher for endemic taxa than for indigenous taxa; single-island endemics than for multi-island endemics; small island endemics than for large island endemics; and for endemics with narrow habitat distributions [24].

Island species may be limited in their ability to cope with climate change due to a range of characteristics, including smaller geographic ranges, limited genetic variation, small colonizing populations, reduced species richness, and poor adaptations to avoid predation [13, 18, 23, 25-27]. The smaller land area of islands provides a smaller realized niche space, which generally translates into very small ranges for island species and especially for endemics [28, 29]. As a result, harmful effects from climate change can encompass an island species' entire habitat more readily than a continental species' habitat [30].

There are three natural ways for species to respond to ongoing climate change. First, given enough time and dispersal they can shift to more favorable habitats elsewhere, thus changing their distribution [31-33]. Second, they can adjust to new environments through behavioural or physiological alterations [34]. Third, they can adapt through genetic changes via the process of evolution [35-37]. Failure to adjust or adapt can lead to the most extreme outcome of climate change, species extinction [38]. We undertook a literature review to examine the impacts of climate change on the terrestrial biodiversity of the Pacific region. Our review investigated terrestrial vertebrate and vascular plant species found by IUCN to be threatened by climate change and severe weather, in order to identify any trends in species characteristics within this group. We then reviewed the literature on the observed and potential impacts of climate change and the possible consequences for the terrestrial biodiversity of the region, focusing on the species' characteristics identified earlier.

Trends in species' characteristics threatened by climate change and severe weather

We selected all terrestrial amphibian, bird, mammal, reptile and vascular plant species from the developing island nations in Oceania (excluding Australia and New Zealand) listed on the IUCN website as threatened by climate change and severe weather [9]. This yielded 305 species, of which 10 were data deficient, 97 were of least concern, 42 were near threatened, 78 were vulnerable, 44 were endangered, and 34 were critically endangered. We further scrutinized the information on each species on the IUCN website to identify any trends in specific characteristics that may have led to climate change and severe weather being listed as a threat for that species. The species' characteristics thus identified were grouped into two categories: one that would make a species vulnerable to the *direct* impacts of climate change, and one that increases a species' vulnerability to climate change *indirectly*, such as habitat reduction caused by sea level rise (Appendix 3). The large variation in numbers of species identified within each class could be due to some groups, such as birds and mammals, being the focus of more research than amphibians, which are a poorly known group with over 1,000 species worldwide categorized as data deficient by the IUCN [39]. The following sections provide an overview of the literature on observed and potential impacts of climate change on the terrestrial biodiversity of the Pacific region, with a focus on the species' characteristics identified in this section.

Climate change impacts on terrestrial flora

The Pacific region has high levels of diversity for vascular and non-vascular plant species, and some countries have exceptional levels of endemic species [40]. For example, New Caledonia contains approximately 3,371 native species of vascular plants, of which 74% are considered endemic [41], while endemism levels are as high as 80% in Papua New Guinea [42] and 90% in Hawaii [43, 44]. Increasing atmospheric temperatures will have substantial impacts on endemic species that have highly restricted distributions in only a few localities [45]. Over 20% of all angiosperm and gymnosperm species in New Caledonia fit into this category [41]. Approximately 48% of the vascular plants identified by Wulff and co-workers [41] to be directly threatened by climate change are endemic to single islands or archipelagos in the Pacific region, with over 90% of the endemics being found in New Caledonia.

Island plant species with restricted ranges are less able to migrate to suitable habitats than mainland plants [46], and the low dispersal ability of many island plant endemics will also hinder migration [43]. Altitudinal shifts in plant distributions may be possible on high islands, but not on small, low-lying islands [43]. Plant community types in the Pacific region will likely undergo fine-scale shifts in species distributions [42]. For example, an upward expansion of fire-adapted grasses along a warming elevation gradient has been recorded in Hawaii [47]. Similarly, increased mortality of an iconic species, Haleakalā silversword (*Argyroxyphium sandwicense*), is associated with warmer and drier trends at high elevations in Hawaii [48]. Such shifts in distribution will depend on the tolerance ranges for each species. Species with broad ecological tolerances may be able to accommodate suitable climate as it changes.

However, species with narrow ranges may not be able to cope with the predicted rate of climate change, which may move them outside their climatic niche within only one or two plant generations [42]. Other climate change related impacts such as changes in cyclone frequency and severity could cause changes in relative species' abundances, favouring disturbance-specialist species and therefore, new forest turnover rates [49, 50].

Climate change will have substantial impacts on ecosystems that only occur in regions with a specific combination of climatic variables, such as tropical dry forests and tropical rainforests (Fig. 2). Tropical dry forests, for example, occur in frost-free regions with an annual rainfall of 500 – 2,000 mm and a distinctive dry season lasting 4 to 7 months [51]. These ecosystems are highly threatened in the Pacific region [52, 53], with only <10% of their original cover remaining and almost all remaining fragments less than 100 ha [54], making dry forest species highly vulnerable to the impacts of climate change. Species vulnerability modelling by Fortini and co-workers [55] showed that dry forest species were much more vulnerable to climate change than species from any other habitat types in Hawaii. Tropical dry forests contain a number of endemic plant species with small geographical ranges in only one or two localities [56], such as the endemic *Diospyros* genus and *Ancistrachne numaeensis* in New Caledonia [57] and the rare and potentially highly endangered *Cynometra falcata* and *Guettarda wayaensis* in Fiji [58]. Such species, with highly restricted spatial ranges and very specific rainfall requirements, are extremely vulnerable to climate change [29, 46].

Tropical rainforests in the Pacific region occur in areas with higher levels of rainfall (> 2,400 mm) and lack the distinctive dry season typical of tropical dry forests [57, 58]. These rainforests contain diverse flora with high levels of endemism. For example, in New Caledonia, over 82% of species found in rainforests are endemic and may be restricted to one or two localities, such as two rainforest palms, *Pritchardiopsis jeanneneyi*, and *Lavoixia macrocarpa* [57, 59]. Climate and especially rainfall regime play an important role in the occurrence of tropical dry forests and rainforests; climate change will impact the local climates within such ecosystems. Species with highly restricted ranges in these ecosystems may not be able to persist under the projected climatic changes for the region. On the other hand, some species, such as Acacia koa (*Metrosideros polymorpha*), which occurs across broad climatic gradients in tropical dry forests [60], may have enough phenotypic plasticity to allow it to adapt to new climatic conditions [46]. However, the occurrence of many endemic plants with narrow distributions on islands suggests that most *in situ* speciation on islands occurred within specific habitats and climate zones, thus making them especially vulnerable to climate change [24, 42, 43].

Any changes in species' distributions and population sizes that may occur in response to changing temperature and rainfall will most likely be observed near climatically determined limits of species' ranges. Increasing atmospheric temperatures will lead to the disappearance of cold climatic zones on higher mountains and isolated mountain ranges. These support montane ecosystems such as cloud forests, where high levels of local endemism can be found in the Pacific region [61, 62]. Habitat for species unable to survive and reproduce in warmer climates will shift upslope and shrink in area [63] (Fig. 2). Changes in cloud cover, humidity and rainfall associated with climate change might disrupt the highly specific conditions necessary to sustain cloud forests [44, 64-66]. Indeed, a substantial reduction in the size of glaciers in New Guinea has already been observed, and a recent estimated warming of 1°C suggests that freezing heights may have already shifted upslope with warmer temperatures and reduced rainfall [67]. Cloud forests that are already restricted to the very highest elevations on some islands in Micronesia and French Polynesia may disappear even with small changes in climatic regime. This could increase rates of species extinction and biodiversity loss, particularly as colonization of new habitats such as those with novel climatic regimes occurs relatively infrequently in the biota of remote Pacific islands [43]. Changes in ocean and mean air temperature in the range of 2°C to 2.5°C could lead to an upward shift of 360 m–450 m in native species' temperature tolerance zones in Hawaiian montane cloud forests, and similar shifts are projected for many other tropical islands [44]. Changes in vegetation response since 1960 have been observed in Papua New Guinea, with shrubby regrowth above the current tree line and the development of grasslands on former moraine [67]. Observations in the 20th century and model projections indicate that warming will occur faster at high elevations than at low elevations [68-70]. Many current tropical montane climates, which exhibit high levels of endemicity, are projected to disappear entirely by the year 2100, with disproportionate impacts on global biodiversity [71, 72].

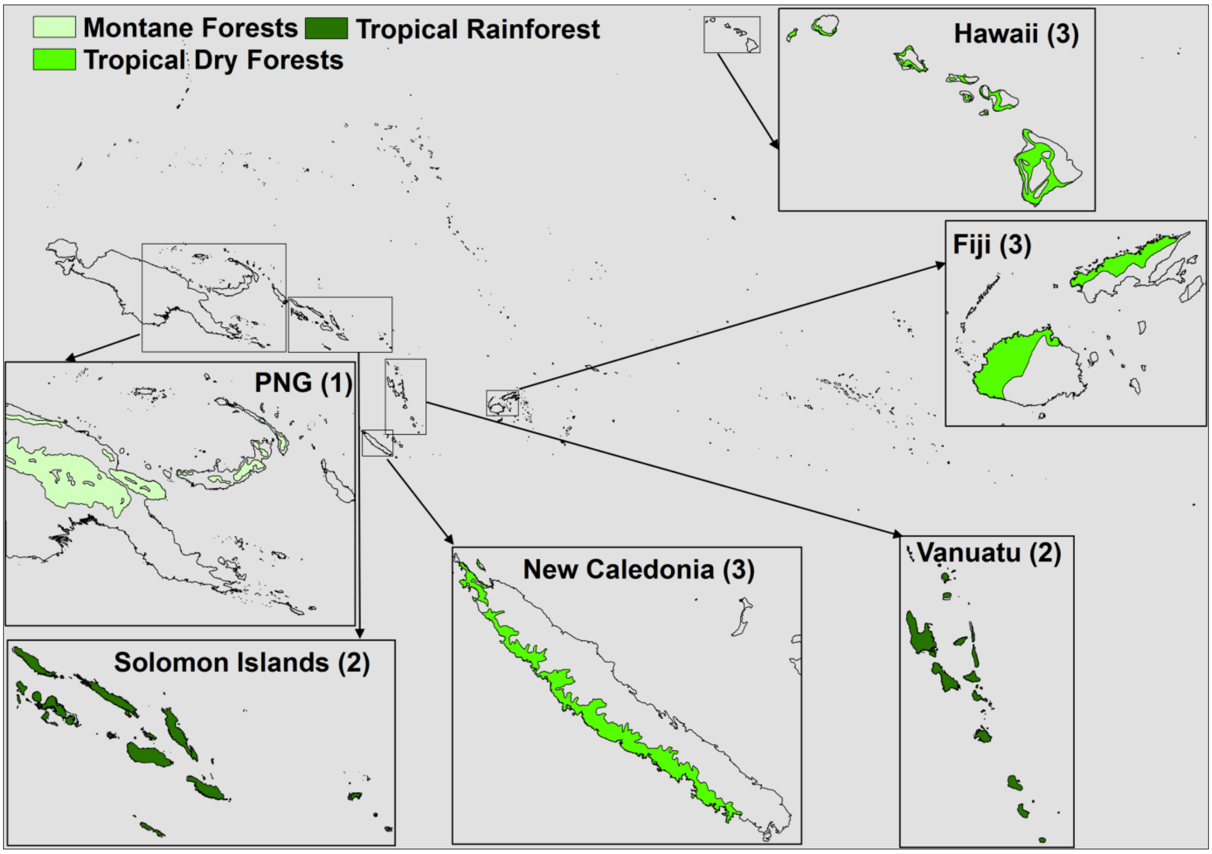

Fig. 2. Summary of climate change impacts on terrestrial flora. (1) Montane Forests: warming temperatures cause cold climatic zones to disappear leading to an upslope shift and shrinking of habitat for montane species, putting large numbers of endemic species at increased risk of extinction. (2) and (3) Tropical Rainforests and Dry Forests: changes in rainfall regimes cause shrinking of habitat for tropical dry and moist forest species. Species that are found in only one or two localities are at increased risk of extinction.

Climate change impacts on terrestrial vertebrate fauna

Ectotherms

Terrestrial ectotherms are likely to be highly vulnerable to the impacts of climate change, because environmental temperature has a strong influence on key physiological functions such as movement, growth, and reproduction [73]. Ectotherms in tropical regions show limited adaptability to increases beyond their threshold for upper thermal limits [74]. In general, reptiles have narrower distributional ranges than other vertebrates such as birds [75]. Lizards, in particular, are unable to evolve fast enough to adapt to current climate change because they are genetically programmed to specific thermal preferences [36]. The combination of small range and narrow niche requirements makes reptiles highly vulnerable to the impacts of climate change.

The Pacific region reportedly has 672 species of amphibians and reptiles, although this record may be incomplete [76]. A more recent estimate for the Papuan Region alone (PNG and Solomon Islands) is 793 currently known species [77]. Species with narrow ecological tolerances, small geographic ranges, narrow altitudinal bands, and species endemic to small islands are the most vulnerable to the impacts of climate change [77]. The mountainous areas in Papua New Guinea support large numbers of frog and lizard species with such attributes [78, 79]. An analysis of the herpetofauna of the Papuan Region indicated that approximately 35 species of frogs, several species of lizards and several species of snakes have small populations on islands or mountain summits, making them vulnerable to extinction due to climate-change-related habitat loss [77] (Fig. 3a).

New species and range extensions of known species are still being discovered for the herpetofauna of the Pacific region [80-83]. A newly discovered species of cross frog, *Oreophryne ezra,* has only been recorded from a single small patch of cloud forest, less than 1km^2 in total extent, at elevations ranging from 630 m–800 m in PNG [80]. Species with such small habitats in cloud forests are highly vulnerable to loss of habitat through climatic warming and changes in rainfall or cloud cover [80].

Species that occur exclusively on low-lying atolls face particular challenges, such as the native lizards of the genus *Emoia* (Family Scincidae) that are widespread on reef islands in Federated States of Micronesia, Marshall Islands, Tokelau and Tonga. The Micronesia forest skink *Emoia boettgeri* is endemic to Marshall Islands and has the most limited range of the 11 species of lizards (six geckos, five skinks) found on reef islands of Micronesia [84, 85]. Climate change impacts such as sea level rise, increased storm frequency and intensity, and saltwater intrusion destroy the lizard's critical forest habitat [9]. The restricted area of the coral atolls provides limited opportunities for this species to accommodate any changes in climate (Fig. 3b). The main option available to species on coral atolls is to shift to neighbouring atolls which might have some favourable habitat, but such range shifts are difficult given the vast expense of ocean between islands. Additionally, species from the *Emoia* genus have an extremely limited capacity for active overwater dispersal, relying mainly on chance events such as rafting on floating debris.

Endotherms

Terrestrial endotherms such as birds have high body temperatures and metabolic rates and little capacity for fat storage, and they generally exist on thermal physiological margins; thus any changes in temperature may push them over their physiological limits [88]. The physiological boundaries in tropical birds are much narrower than in temperate species, limiting their ability to cope with changing climate [88]. The islands in the Pacific region are home to many restricted range species (<50,000 km^2) from a variety of families such as Drepanididae (Hawaiin honeycreepers), Zosteropidae (White-eyes) and Paradisaeidae (birds of paradise from PNG) [89] (Fig. 3b). The majority of the species in these families are small-island colonizers that have evolved in isolation and have altitudinal or spatial habitat restrictions, their preferred habitat type generally being forests. Mountaintop-restricted bird species with narrow elevational ranges are particularly susceptible to the impacts of climate change since they have a much smaller area of occupancy [90-92]. On the other hand, species with a broad elevational breadth have populations in more habitats, providing greater plasticity in their habitat requirements [88] and making them less vulnerable to the impacts of climate change [93]. An analysis of the distributions of terrestrial and freshwater species in Melanesia indicated that over 50 percent were strongly to moderately vulnerable to climate change impacts based on their elevational spans [88]. Increasing temperatures may reduce many montane species' ranges, causing them to shift to higher elevations or to become locally or globally extinct, particularly in the case of endemic species restricted to tropical montane highlands [94-97].

Changes in climate will also affect the seasonal availability of food, affecting the many species of frugivorous and nectarivorous birds in the Pacific. Such species forage vast areas and use different islands when food is available, and any alterations to these cycles could affect the whole population [88]. Furthermore, many small islands such as atolls provide nesting sites for breeding migratory species. For example, species like the Bristle-thighed Curlews (*Numenius tahitiensis*) that winter on small Pacific islands could be severely impacted if rising sea levels and storm surges destroy habitat on the small islands and atolls that are important breeding destinations or stopovers for migratory species [88]. However, some atoll dwellers, such as the Eastern Polynesian reed-warblers (genus *Acrocephalus*) may be likely to survive rises in sea levels as they have done in the past [98, 99].

Populations of *Acrocephalus* sp. currently occur on carbonate islands that have elevations exceeding 3m, which provided refugia for the birds during the Quaternary sea-level variations [99].

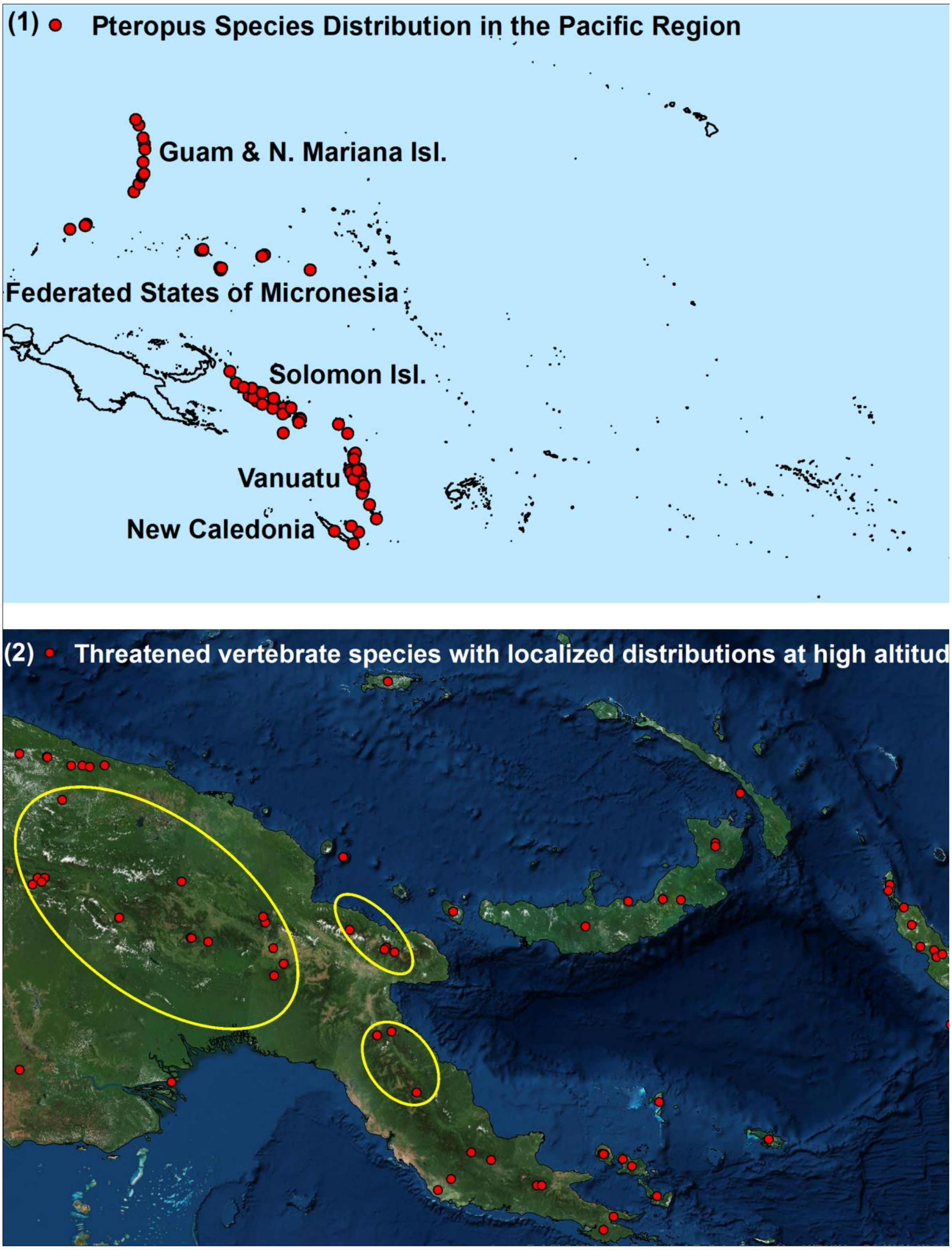

Fig. 3a. Summary of climate change impacts on terrestrial fauna. (1) Extreme temperatures cause mortality in some species such as *Pteropus* spp. (Flying foxes) [9]. (2) Species on mountain summits with highly localized distribution are at increased risk of extinction [86].

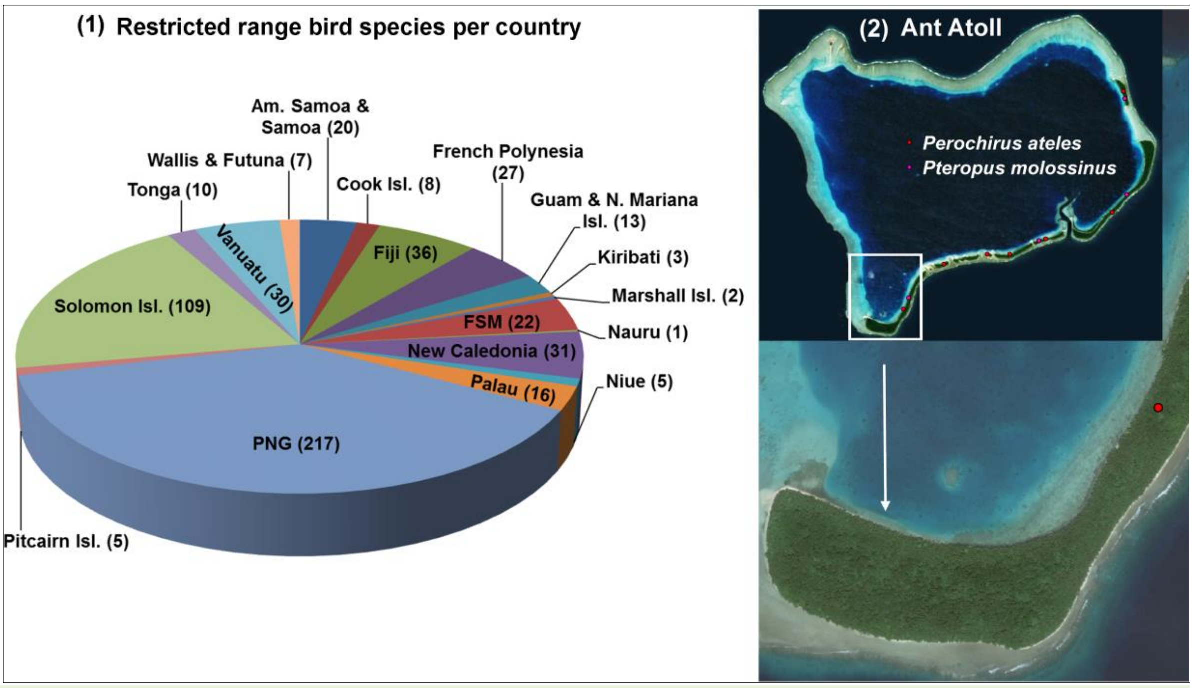

Fig. 3b. Summary of climate change impacts on terrestrial fauna. (1) Restricted range species such as the many bird species of the Pacific region are at increased risk of extinction from habitat loss associated with climate change [87]. (2) Atoll species are at increased extinction risk due to habitat loss from sea level rise (occurrence of two threatened species on Ant Atoll in the Federated States of Micronesia) [9, 86].

The native mammal fauna of the Pacific region is composed mainly of bats, marsupials, and rodents from the Australopapuan region [100, 101]. These are mainly found on islands with large land areas and high elevations, such as the Bismarck and Solomon archipelagos, which host many species of endemic mammals [102]. No native mammals including bats can be found on archipelagos composed of low-lying, sandy islands such as Marshall Islands, Tuvalu, and Tokelau [102]. These islands have low plant diversity not conducive to the persistence of large mammal populations [56].

Mammals are directly affected by changes in climate, particularly extreme temperatures [103] and indirectly through extreme weather events such as tropical storms [104]. Extreme temperatures cause large numbers of deaths from hyperthermia in flying foxes (*Pteropus* species) [105] (Fig. 3a). Populations of Pacific flying fox, *Pteropus tonganus,* and Samoa flying fox, *P. samoensis,* also suffered high mortality following a 1990 typhoon in Samoa and American Samoa due to changes in their feeding behaviour that made them more vulnerable to predation by domestic dogs, cats and pigs [106]. In some cases indirect impacts such as increased hunting by humans after a storm led to higher mortality rates for *Pteropus* species on Mariana Islands, Samoa, and Vanuatu [107]. Susceptibility to extremely high temperatures has also been reported in the long- and short-beaked echidnas, particularly if they do not have access to cooler shelters, shrinking their distribution in areas with substantial temperature increases [108]. Species of echidnas restricted to montane environments [109] will face the prospect of habitat loss as increasing temperatures destroy montane ecosystems [71, 72]. Sea level rise will impact a large number of range-restricted endemic vertebrates, and 37 to 118 endemic species face the threat of extinction from a projected sea level rise of one to three meters, respectively, in the Pacific and Southeast Asia alone [110].

Interacting Factors

Terrestrial biodiversity in the Pacific region has been significantly affected by increasing human populations and the associated increase in agriculture. Clearing of forested areas and commercial logging have caused substantial losses in forest habitats [111]. Habitat destruction and invasive species are the two main causes of species' extinctions in this region [112]. Invasive vertebrate and vascular plant species have caused large numbers of extinctions on islands [21, 113-115]. Pollution and overexploitation are also having severe impacts on terrestrial biodiversity in the region [111].

Climate change may interact synergistically with these other threats, exacerbating the impacts of climate change and ultimately causing multiple extinctions [46, 90, 116, 117]. Little is known about many of these interactions and how they will impact the biota of the Pacific region [43], but research on honeycreepers (Drepanidae) on the islands of Kauai and Hawaii shows that the combined impacts of invasive species, historical land-use change, and anthropogenic climate change may cause the extinction of many remaining species [118]. Changes in land-use associated with agricultural practices have caused habitat fragmentation, which together with climate change could intensify adverse impacts on restricted range and dispersal-limited species [46]. The ability of species to persist in the long term is highly dependent on their geographical range and dispersal ability [20, 24, 119], and traits such as restricted range and ecological specialisation can act synergistically with climate change to increase extinction risk [117]. Such traits are common in the terrestrial species discussed in this review. Furthermore, species that are found in small populations in only a few localities are vulnerable to natural disasters such as cyclones, which are common in the Pacific region. Further research is needed on how climate change will interact with other threats outlined in this section. The vegetation covering Earth's continents has a profound impact on its climate, and anthropogenic land cover change from agriculture, forestry and urbanization will thus have a substantial impact, not only on Earth's climate but also on the carbon cycle [120]. This is a complex issue that will not be discussed in this review but has received detailed treatment elsewhere (see [120] and references therein).

Conclusions

The small island nations of the Pacific region contribute a small proportion of global greenhouse gas emissions but will experience disproportionate consequences from global climate change. This region contains three of the world's global biodiversity hotspots, with many endemic species that are vulnerable to and already experiencing many effects of anthropogenic climate change, such as sea level rise, changes in rainfall and temperature, and more extreme weather events. The impacts of activities such as habitat destruction through mining and logging, agricultural expansion, overexploitation of natural resources, pollution, and coastal development are exacerbated by the impacts of climate change.

An accurate assessment of the impacts of climate change is hampered by limited ecological data on species, especially species with highly restricted ranges and those that are found in only one or two localities. Published literature on the physiology of island species in relation to predicted climatic changes is rare. New species are still being discovered in the region, some previously distinct species are being merged, range expansions are being discovered in species thought to be endemic to one region, and new extinctions are still being recorded. These factors will all lead to changes in endemism and biodiversity estimates for the islands of the region [42, 77, 88].

There has been a lack of intensive survey work in the region to identify and map the distribution of species [78, 121]. Thus, many countries have neither complete national lists of threatened species nor complete, current IUCN Red Lists, and many species of the region are listed as data deficient by the IUCN [122]. Collection of baseline data on species' ecology, distributions, and endemic status is a priority, necessary both to assess the impacts of climate change on the species of the region and to devise effective conservation strategies. Projects such as the Pacific-Asia Biodiversity Transect

(PABITRA) network may provide baseline data and fill some of the existing knowledge gaps so that more accurate climate change assessments can be undertaken [62, 123, 124]. Other regional coordination efforts also focus on gathering baseline scientific data on threatened species, raising awareness about the value of biodiversity among local communities, and assisting countries in the design and implementation of a National Biodiversity Strategic Action Plan (NBSAP) [16, 125, 126, 127, 128, 129]. Some of these have been highly successful, resulting in baseline inventories of the flora and fauna of relatively untouched regions [126] and highly detailed scientific information on current and future climate projections for individual countries [16]. However, other efforts, such as the development of NBSAPs, have had limited success in some countries due to lack of funds and available personnel and skills [130].

The loss of habitat on island biodiversity hotspots caused by sea level rise has been investigated [3, 110], although very small reef islands could not be assessed due to lack of elevation data. There is an urgent need for fine resolution elevation data for the very small reef islands in this region in order to measure area loss due to sea level rise, but acquisition of such data is too costly for some Pacific Island countries. Because space-restricted reef islands preclude range shifts in species whose physiological tolerances have been exceeded, there is significant danger of loss of endemic biodiversity and the consequent loss of evolutionary potential. It is therefore vital to identify climate refugia that could be used for translocations. However, such refugia will have to be selected with care to provide a safe environment for the persistence of endemic species, particularly poorly dispersed ones [131, 132].

The unique biogeographical processes on islands that have given rise to such high levels of endemism have also endowed species with characteristics that make them highly susceptible to climate change. The accelerated *rate* of climate change, limiting the capacity for rapid adaptation, and the limited amount of suitable habitat on small islands suggest that the consequences could be severe for the biodiversity of the region.

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References

[1] IPCC. 2013. Summary for Policymakers. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Stocker T.F., Qin D., Plattner G.-K., Tignor M., Allen S.K., Boschung J., Nauels A., Xia Y., Bex V. and Midgley P.M. (Eds.), Cambridge University Press, Cambridge.

[2] Nicholls R.J. and Cazenave A. 2010. Sea-Level Rise and Its Impact on Coastal Zones. *Science* 328: 1517-1520.

[3] Bellard C., Leclerc C. and Courchamp F. 2014. Impact of sea level rise on the 10 insular biodiversity hotspots. *Global Ecology and Biogeography* 23: 203-212.

[4] Nurse L.A., McLean R.F., Agard J., Briguglio L.P., Duvat-Magnan V., Pelesikoti N., Tompkina E. and Webb A. 2014. Small islands. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Barros V.R., Field C.B., Dokken D.J., Mastrandrea M.D., Mach K.J., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P.R., and White L.L. (Eds.), pp. 1613-1654. Cambridge University Press, Cambridge.

[5] Keppel G., Lowe A.J. and Possingham H.P. 2009. Changing perspectives on the biogeography of the tropical South Pacific: influences of dispersal, vicariance and extinction. *Journal of Biogeography* 36: 1035-1054.

[6] Neall V.E. and Trewick S.A. 2008. The age and origin of the Pacific islands: a geological overview. *Philosophical Transactions of the Royal Society B: Biological Sciences* 363: 3293-3308.

[7] Myers N. 1990. The biodiversity challenge: expanded hotspots analysis. *Environmentalist* 10: 243-256.

[8] Myers N., Mittermeier R.A., Mittermeier C.G., da Fonseca G.A.B. and Kent J. 2000. Biodiversity hotspots for conservation priorities. *Nature* 403: 853-858.

[9] IUCN. 2015. Red List of threatened species. Available from http://www.iucnredlist.org/ (accessed August 21, 2015).

[10] Lobban C.S. and Schefter M. 1997. *Tropical Pacific Island Environments*. University of Guam Press, Guam.

[11] Kingsford R.T. and Watson J.E.M. 2011. Climate Change in Oceania – A synthesis of biodiversity impacts and adaptations. *Pacific Conservation Biology* 17: 270-284.

[12] Brodie G., Pikacha P. and Tuiwawa M. 2013. Biodiversity and Conservation in the Pacific Islands: Why Are We Not Succeeding? In: *Conservation Biology: Voices from the Tropics*. Sodhi N.S., Gibson L. and Raven P.H. (Eds), pp. 181-187. Wiley Blackwell, New Jersey.

[13] Jupiter S., Mangubhai S. and Kingsford R.T. 2014. Conservation of Biodiversity in the Pacific Islands of Oceania: Challenges and Opportunities. *Pacific Conservation Biology* 20: 206-220.

[14] Keppel G., Morrison C., Meyer J.-Y. and Boehmer H.J. 2014. Isolated and vulnerable: the history and future of Pacific Island terrestrial biodiversity. *Pacific Conservation Biology* 20: 136-145.

[15] Henderson-Sellers A., Zhang H., Berz G., Emanuel K., Gray W., Landsea C., Holland G., Lighthill J., Shieh S-L., Webster P. and McGuffie K. 1998. Tropical Cyclones and Global Climate Change: A Post-IPCC Assessment. *Bulletin of the American Meteorological Society* 79: 19-38.

[16] Australian Bureau of Meteorology and CSIRO. 2014. Climate Variability, Extremes and Change in the Western Tropical Pacific: New Science and Updated Country Reports., Australian Bureau of Meteorology and Commonwealth Scientific and Industrial Research Organisation, Melbourne.

[17] Woodroffe C.D. 2008. Reef-island topography and the vulnerability of atolls to sea-level rise. *Global and Planetary Change* 62: 77-96.

[18] Cox C.B. and Moore P.D. 2010. *Biogeography: An ecological and evolutionary approach*. Wiley, New Jersey.

[19] Davis M.A. 2003. Biotic Globalization: Does Competition from Introduced Species Threaten Biodiversity? *BioScience* 53: 481-489.

[20] Pimm S., Raven P., Peterson A., Şekercioğlu Ç.H. and Ehrlich P.R. 2006. Human impacts on the rates of recent, present, and future bird extinctions. *Proceedings of the National Academy of Sciences* 103: 10941-10946.

[21] Sax D.F. and Gaines S.D. 2008. Species invasions and extinction: The future of native biodiversity on islands. *Proceedings of the National Academy of Sciences* 105: 11490-11497.

[22] Fordham D.A. and Brook B.W. 2010. Why tropical island endemics are acutely susceptible to global change. *Biodiversity and Conservation* 19: 329-342.

[23] Loehle C. and Eschenbach W. 2012. Historical bird and terrestrial mammal extinction rates and causes. *Diversity and Distributions* 18: 84-91.

[24] Sakai A., Wagner W.L. and Mehrhoff L.A. 2002. Patterns of endangerment in the Hawaiian flora. *Systematic Biology* 51: 276-302.

[25] Cronk Q.C.B. 1997. Islands: stability, diversity, conservation. *Biodiversity and Conservation* 6: 477-493.

[26] Wright S.D., Gillman L.N., Ross H.A. and Keeling D.J. 2009. Slower tempo of microevolution in island birds: Implications for conservation biology. *Evolution* 63: 2275-2287.

[27] Corlett R.T. 2010. Invasive aliens on tropical East Asian islands. *Biodiversity and Conservation* 19: 411-423.

[28] Altaba C. 2014. Extinction Resilience of Island Species: An Amphibian Case and a Predictive Model. *Diversity* 6: 43-71.

[29] Harter D.E.V., Irl S.D.H., Seo B., Steinbauer M.J., Gillespie R., Triantis K.A., Fernández-Palacios J.-M. and Beierkuhnlein C. 2015. Impacts of global climate change on the floras of oceanic islands – Projections, implications and current knowledge. *Perspectives in Plant Ecology, Evolution and Systematics* 17: 160-183.

[30] Pimm S.L. 2002. The Dodo went extinct (and other ecological myths). *Annals of the Missouri Botanical Garden* 89: 190-198.

[31] Parmesan C. 2006. Ecological and Evolutionary Responses to Recent Climate Change. *Annual Review of Ecology, Evolution, and Systematics* 37: 637-669.

[32] Thomas C.D. 2010. Climate, climate change and range boundaries. *Diversity and Distributions* 16: 488-495.

[33] Hughes L. 2000. Biological consequences of global warming: is the signal already apparent? *Trends in Ecology & Evolution* 15: 56-61.

[34] Charmantier A., McCleery R.H., Cole L.R., Perrins C., Kruuk L.E.B. and Sheldon B.C. 2008. Adaptive Phenotypic Plasticity in Response to Climate Change in a Wild Bird Population. *Science* 320: 800-803.

[35] Staudinger M.D., Carter S.L., Cross M.S., Dubois N.S., Duffy J.E., Enquist C., Griffis R., Hellmann J.J., Lawler J.J., O'Leary J., Morrison S.A., Sneddon L., Stein B.A., Thompson L.M. and Turner W. 2013. Biodiversity in a changing climate: a synthesis of current and projected trends in the US. *Frontiers in Ecology and the Environment* 11: 465-473.

[36] Sinervo B., Méndez-de-la-Cruz F., Miles D.B. et al. 2010. Erosion of lizard diversity by climate change and altered thermal niches. *Science* 328: 894-899.

[37] Gienapp P., Teplitsky C., Alho J.S., Mills J.A. and Merila J. 2008. Climate change and evolution: disentangling environmental and genetic responses. *Molecular Ecology* 17: 167-178.

[38] Bellard C., Bertelsmeier C., Leadley P., Thuiller W. and Courchamp F. 2012. Impacts of climate change on the future of biodiversity. *Ecology Letters* 15: 365-377.

[39] Stuart S.N., Chanson J.S., Cox N.A., Young B.E., Rodrigues A.S.L., Fischman D.L. and Waller R.W. 2004. Status and Trends of Amphibian Declines and Extinctions Worldwide. *Science* 306: 1783-1785.

[40] Gillespie T.W., Keppel G., Pau S., Price J.P., Jaffré T. and O'Neill K. 2013. Scaling species richness and endemism of tropical dry forests on oceanic islands. *Diversity and Distributions* 19: 896-906.

[41] Wulff A.S., Hollingsworth P.M., Ahrends A., Jaffré T., Veillon J.-M., L'Huillier L. and Fogliani B. 2013. Conservation priorities in a biodiversity hotspot: Analysis of narrow endemic plant species in New Caledonia. *PLoS ONE* 8: e73371.

[42] James S.A. 2008. Climate Change Impacts on Native Plant Communities in Melanesia. In: *Climate Change and Biodiversity in Melanesia (CCBM) Bishop Museum Technical Report 42(8)*. Leisz S.J. and Burnett B. (Eds), pp. 1-15. Bishop Museum, Honolulu.

[43] Gillespie R.G., Claridge E.M. and Roderick G.K. 2008. Biodiversity dynamics in isolated island communities: interaction between natural and human-mediated processes. *Molecular Ecology* 17: 45-57.

[44] Loope L.L. and Giambelluca T.W. 1998. Vulnerability of island tropical montane cloud forests to climate change, with special reference to east Maui, Hawaii. *Climatic Change* 39: 503-517.

[45] Lowry P.P. 1998. Diversity, endemism, and extinction in the flora of New Caledonia: a review. In: *Proceedings of the International Symposium on Rare, Threatened, and Endangered Floras of Asia and the Pacific*. Academia Sinica, Taipei.

[46] Caujape-Castells J., Tye A., Crawford D.J., Santos-Guerra A., Sakai A., Beaver K., Lobin W., Florens F.B.V., Moura M., Jardim R., Gómes I. and Kueffer C. 2010. Conservation of oceanic island floras: Present and future global challenges. *Perspectives in Plant Ecology Evolution and Systematics* 12: 107-129.

[47] Angelo C.L. and Daehler C.C. 2013. Upward expansion of fire-adapted grasses along a warming tropical elevation gradient. *Ecography* 36: 551-559.

[48] Krushelnycky P.D., Loope L.L., Giambelluca T.W., Starr F., Starr K., Drake D.R., Taylor A.D. and Robichaux R.H. 2013. Climate-associated population declines reverse recovery and threaten future of an iconic high-elevation plant. *Global Change Biology* 19: 911-922.

[49] Webb E.L., Seamon J.O. and Fa'aumu S. 2011. Frequent, low-amplitude disturbances drive high tree turnover rates on a remote, cyclone-prone Polynesian island. *Journal of Biogeography* 38: 1240-1252.

[50] Lugo A.E. 2008. Visible and invisible effects of hurricanes on ecosystems: an international review. *Austral Ecology* 33: 368-398.

[51] Murphy P.G. and Lugo A.E. 1986. Ecology of tropical dry forest. *Annual Review of Ecology and Systematics* 17: 67-88.

[52] Gillespie T.W. and Jaffré T. 2003. Tropical dry forests in New Caledonia. *Biodiversity and Conservation* 12: 1687-1697.

[53] Pau S., Gillespie T.W. and Price J.P. 2009. Natural history, biogeography, and endangerment of Hawaiian dry forest trees. *Biodiversity and Conservation* 18: 3167-3182.

[54] Gillespie T.W., O'Neill K., Keppel G., Pau S., Meyer J.-Y., Price J.P. and Jaffré T. 2014. Prioritizing conservation of tropical dry forests in the Pacific. *Oryx* 48: 337-344.

[55] Fortini L., Price J., Jacobi J., Vorsino A., Burgett J., Brinck K., Amidon F., Miller S., \`Ohukani\`ohi\`a Gon III S., Koob G. and Paxton E. 2013. A landscape-based assessmentof climate change vulnerability for all native Hawaiian plants. Hawai'i Cooperative Studies Unit, University of Hawaii, Technical Report HCSU-044.

[56] Mueller-Dombois D. and Fosberg F.R. 1998. *Vegetation of the Tropical Pacific Islands*. Springer-Verlag, New York.

[57] Jaffre T., Bouchet P. and Veillon J.-M. 1998. Threatened plants of New Caledonia: Is the system of protected areas adequate? *Biodiversity and Conservation* 7: 109-135.

[58] Keppel G. and Tuiwawa M.V. 2007. Dry zone forests of Fiji: Species composition, life history traits, and conservation. *New Zealand Journal of Botany* 45: 545-563.

[59] Jaffré T. and Veillon J.-M. 1989. Morphology, distribution and ecology of palms in New Caledonia. In: *Palms of the south-west Pacific: their origin, distribution and description*. Dowe J.L. (Ed), pp. 158-168. Publication Fund, Palm and Cycad Societies of Australia, Milton, Queensland, Australia.

[60] Ares A., Fownes J.H. and Sun W. 2000. Genetic Differentiation of Intrinsic Water-Use Efficiency in the Hawaiian Native Acacia koa. International *Journal of Plant Science* 161: 909-915.

[61] Takeuchi W. 2003. Plant discoveries from PABITRA-related exploration in Papua New Guinea. *Organisms Diversity & Evolution* 3: 77-84.

[62] Tuiwawa M. 2005. Recent Changes in the Upland Watershed Forest of Monasavu, a Cloud Forest Site along the PABITRA Gateway Transect on Viti Levu, Fiji. *Pacific Science* 59: 159-164.

[63] Raxworthy C.J., Pearson R.G., Rabibisoa N., Rakotondrazafy A.M., Ramanamanjato J.-B., Raselimanana A.P., Wu S., Nussbaum R.A. and Stone D.A. 2008. Extinction vulnerability of tropical montane endemism from warming and upslope displacement: a preliminary appraisal for the highest massif in Madagascar. *Global Change Biology* 14: 1703-1720.

[64] Still C., Foster P.N. and Schneider S.H. 1999. Simulating the effects of climate change on troical montane cloud forests. *Nature* 398: 608-610.

[65] Mimura N., Nurse L., McLean R.F., Agard J., Briguglio L., Lefale P., Payet R. and Sem G. 2007. Small islands. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Parry M.L., Canziani O.F., Palutikof J.P., van der Linden P.J. and Hanson C.E. (Eds), pp. 687-716. Cambridge University Press, Cambridge.

[66] Nadkarni N.M. and Solano R. 2002. Potential effects of climate change on canopy communities in a tropical cloud forest: an experimental approach. *Oecologia* 131: 580-586.

[67] Hope G. 2008. Palaeoecology and Resilience in Melanesia: How can palaeoecology contribute to climate change response planning? In: *Climate change and biodiversity in Melanesia (CCBM) Bishop Museum Technical Report 42(4)*. Leisz S.J. and Burnett B. (Eds), pp. 1-10. Bishop Museum, Honolulu.

[68] Giambelluca T.W., Diaz H.F. and Luke M.S.A. 2008. Secular temperature changes in Hawai'i. *Geophysical Research Letters* 35: L12702.

[69] Bradley R.S., Vuille M., Diaz H.F. and Vergara W. 2006. Threats to Water Supplies in the Tropical Andes. *Science* 312: 1755-1756.

[70] Foster P. 2001. The potential negative impacts of global climate change on tropical montane cloud forests. *Earth-Science Reviews* 55: 73-106.

[71] Williams J.W., Jackson S.T. and Kutzbac J.E. 2007. Projected distributions of novel and disappearing climates by 2100 AD. *Proceedings of the National Academy of Sciences USA* 104: 5738.

[72] Laurance W.F., Useche D.C., Shoo L.P. et al. 2011. Global warming, elevational ranges and the vulnerability of tropical biota. *Biological Conservation* 144: 548-557.

[73] Deutsch C.A., Tewksbury J.J., Huey R.B., Sheldon K.S., Ghalambor C.K., Haak D.C. and Martin P.R. 2008. Impacts of climate warming on terrestrial ectotherms across latitude. *Proceedings of the National Academy of Sciences* 105: 6668-6672.

[74] Dillon M.E., Wang G. and Huey R.B. 2010. Global metabolic impacts of recent climate warming. *Nature* 467: 704-706.

[75] Anderson S. and Marcus L. 1992. Aerography of Australian Tetrapods. *Australian Journal of Zoology* 40: 627-651.

[76] Allison A. 1996. Zoogeography of amphibians and reptiles of New Guinea and the Pacific region. In: *The origin and evolution of Pacific Island biotas, New Guinea to Eastern Polynesia: patterns and processes*. Keast E. and Miller S.E. (Eds), pp. 407-436. SPB Academic Publishing, Amsterdam.

[77] Allison A. and Leisz S.J. 2009. Analysis of the impacts of climate change on the herpetofauna of the Papuan region (New Guinea to the Solomon Islands). Bishop Museum, Honolulu.

[78] Heads M. 2002. Regional patterns of biodiversity in New Guinea animals. *Journal of Biogeography* 29: 285-294.

[79] Allison A. 1993. Biodiversity and conservation of the fishes, amphibians, and reptiles of Papua New Guinea. In: *Papua New Guinea conservation needs assessment.* Beehler B.M. (Ed), The Biodiversity Support Programme 2: 157-225, Washington D.C.

[80] Kraus F. and Allison A. 2009. New microhylid frogs from the Muller Range, Papua New Guinea. *ZooKeys* 26: 53-76.

[81] Kraus F. 2013. Three new species of Oreophryne (Anura, Microhylidae) from Papua New Guinea. *ZooKeys* 333: 93-121.

[82] Kraus F. 2010. New genus of diminutive microhylid frogs from Papua New Guinea. *ZooKeys* 48: 39-59.

[83] Kraus F. 2010. More Range Extensions for Papuan Reptiles and Amphibians. *Herpetological Review* 41: 246-248.

[84] Buden D.W. 2013. Reptiles of Sorol Atoll, Yap, Federated States of Micronesia. *Pacific Science* 67: 119-128.

[85] Buden D.W. 2011. Reptiles of the Hall Islands, Chuuk State, Federated States of Micronesia. *Pacific Science* 65: 497-505.

[86] ESRI. 2013. ArcGIS Software Version 10.2. Environment Systems Research Institute, Redlands.

[87] Birdlife International. 2015. Endemic Bird Areas. Available from http://www.birdlife.org/datazone/eba (accessed August 5, 2015).

[88] Mack A.L. 2009. Predicting the effects of climate change on Melanesian bird populations: the constraints of too many variables and too few data. In: *Climate change and biodiversity in*

Melanesia (CCBM) Bishop Museum Technical Report 42(9). Leisz S.J. and Burnett B. (Eds), pp. 1-15. Bishop Museum, Honolulu.

[89] Stattersfield A.J., Crosby M.J., Long A.J. and Wege D.C. 1998. Endemic bird areas of the world: Priorities for biodiversity conservation. Birdlife International, Cambridge.

[90] Şekercioğlu Ç.H., Primack R.B. and Wormworth J. 2012. The effects of climate change on tropical birds. *Biological Conservation* 148: 1-18.

[91] Williams S.E., Bolitho E.E. and Fox S. 2003. Climate change in Australian tropical rainforests: an impending environmental catastrophe. *Proceedings of the Royal Society of London B: Biological Sciences* 270: 1887-1892.

[92] Shoo L.P., Williams S.E. and Hero J.-M. 2005. Climate warming and the rainforest birds of the Australian Wet Tropics: Using abundance data as a sensitive predictor of change in total population size. *Biological Conservation* 125: 335-343.

[93] Anciães M. and Townsend Peterson A. 2009. Ecological niches and their evolution among Neotropical manakins (Aves: Pipridae). *Journal of Avian Biology* 40: 591-604.

[94] Shoo L.P., Williams S.E. and Hero J.-M. 2006. Detecting climate change induced range shifts: Where and how should we be looking? *Austral Ecology* 31: 22-29.

[95] Hilbert D.W., Bradford M., Parker T. and Westcott D.A. 2004. Golden bowerbird (Prionodura newtonia) habitat in past, present and future climates: predicted extinction of a vertebrate in tropical highlands due to global warming. *Biological Conservation* 116: 367-377.

[96] Colwell R.K., Brehm G., Cardelús C.L., Gilman A.C. and Longino J.T. 2008. Global Warming, Elevational Range Shifts, and Lowland Biotic Attrition in the Wet Tropics. *Science* 322: 258-261.

[97] Gasner M.R., Jankowski J.E., Ciecka A.L., Kyle K.O. and Rabenold K.N. 2010. Projecting the local impacts of climate change on a Central American montane avian community. *Biological Conservation* 143: 1250-1258.

[98] Cibois A., Beadell J.S., Graves G.R., Pasquet E., Slikas B., Sonsthagen S.A., Thibault J.-C. and Fleischer R.C. 2011. Charting the course of reed-warblers across the Pacific islands. *Journal of Biogeography* 38: 1963-1975.

[99] Cibois A., Thibault J.-C. and Pasquet E. 2010. Influence of quaternary sea-level variations on a land bird endemic to Pacific atolls. *Proceedings of the Royal Society of London B: Biological Sciences* 277: 3445-3451.

[100] Flannery T.F. 1995. *Mammals of the south-west Pacific and Moluccan islands*. Cornell University Press, New York.

[101] Flannery T.F. 1995. *Mammals of New Guinea*. Australian Museum/Reed New Holland, Sydney.

[102] Carvajal A. and Adler G.H. 2005. Biogeography of mammals on tropical Pacific islands. *Journal of Biogeography* 32: 1561-1569.

[103] Cooper N., Freckleton R.P. and Jetz W. 2011. Phylogenetic conservatism of environmental niches in mammals. *Proceedings of the Royal Society B: Biological Sciences* 278: 2384-2391.

[104] Mickleburgh S.P., Hutson A.M. and Racey P.A. 2002. A review of the global conservation status of bats. *Oryx* 36: 18-34.

[105] Welbergen J.A., Klose S.M., Markus N. and Eby P. 2008. Climate change and the effects of temperature extremes on Australian flying-foxes. *Proceedings of the Royal Society B: Biological Sciences* 275: 419-425.

[106] Dashback N. 1990. After the hurricane. *Bats* 8: 14-15.

[107] Pierson E.D. and Rainey W.E. 1992. The biology of flying foxes of the genus Pteropus: a review. In: *Pacific Island Flying Foxes: Proceedings of an International Conservation Conference.* Wilson D.E. and Graham G.L. (Eds), pp. 1-17. US Department of the Interior, Fish and Wildlife Service, Washington D.C.

[108] Ashwell K.W.S., Hardman C.D. and Musser A.M. 2014. Brain and behaviour of living and extinct echidnas. *Zoology* 117: 349-361.

[109] Flannery T.F. and Groves C.P. 1998. A revision of the genus Zaglossus (Monotremata, Tachyglossidae), with description of new species and subspecies. *Mammalia* 62: 367-396.
[110] Wetzel F.T., Beissmann H., Penn D.J. and Jetz W. 2013. Vulnerability of terrestrial island vertebrates to projected sea-level rise. *Global Change Biology* 19: 2058-2070.
[111] Kingsford R.T., Watson J.E.M., Lundquist C.J., Venter O., Hughes L., Johnston E.L., Atherton J., Gawel M., Keith D.A., Mackey B.G., Morley C., Possingham H.P., Raynor B., Recher H.F. and Wilson K.A. 2009. Major Conservation Policy Issues for Biodiversity in Oceania. *Conservation Biology* 23: 834-840.
[112] Sherley G., Timmins S. and Lowe S. 2000. Draft invasive species strategy for the Pacific Islands region. In: *Invasive species in the Pacific: a technical review and draft regional strategy*. Sherley G. (Ed), pp. 1-7. South Pacific Regional Environment Programme, Apia, Samoa.
[113] Steadman D. 2006. *Extinction and Biogeography of Tropical Pacific Birds*. The University of Chicago Press, Chicago.
[114] Rödder D. and Lötters S. 2010. Potential Distribution of the Alien Invasive Brown Tree Snake, Boiga irregularis (Reptilia: Colubridae). *Pacific Science* 64: 11-22.
[115] Sax D.F., Gaines S.D. and Brown J.H. 2002. Species Invasions Exceed Extinctions on Islands Worldwide: A Comparative Study of Plants and Birds. *The American Naturalist* 160: 766-783.
[116] Cahill A.E., Aiello-Lammens E., Fisher-Reid M.C., Hua X., Karanewsky C.J., Ryu H.Y., Sbeglia G.C., Spagnolo F., Waldron J.B., Warsi O. and Wiens J.J. 2012. How does climate change cause extinction? *Proceedings of the Royal Society of London B: Biological Sciences* 280: 20121890. DOI: 10.1098/rspb.2012.1890
[117] Brook B.W., Sodhi N.S. and Bradshaw C.J.A. 2008. Synergies among extinction drivers under global change. *Trends in Ecology & Evolution* 23: 453-460.
[118] Benning T.L., LaPointe D., Atkinson C.T. and Vitousek P.M. 2002. Interactions of climate change with biological invasions and land use in the Hawaiian Islands: Modeling the fate of endemic birds using a geographic information system. *Proceedings of the National Academy of Sciences* 99: 14246-14249.
[119] Jetz W., Wilcove D.S. and Dobson A.P. 2007. Projected Impacts of Climate and Land-Use Change on the Global Diversity of Birds. *PLoS Biology* 5: e157.
[120] Pongratz J., Reick C.H., Raddatz T. and Claussen M. 2009. Effects of anthropogenic land cover change on the carbon cycle of the last millennium. *Global Biogeochemical Cycles* 23: GB4001. DOI:10.1029/2009GB003488
[121] Baillie J.E.M., Turvey S.T. and Waterman C. 2008. Toward monitoring global biodiversity. *Conservation Letters* 1: 18-26.
[122] Morrison C. 2012. Impacts of tourism on threatened species in the Pacific region: a review. *Pacific Conservation Biology* 18: 227-239.
[123] Keppel G. 2005. Botanical Studies within the PABITRA Wet-Zone Transect, Viti Levu, Fiji. *Pacific Science* 59: 165-174.
[124] McClatchey W.C., Sirikolo M.Q., Boe H., Biliki E. and Votboc F. 2005. A Proposed PABITRA Study Area on Lauru Island, Western Solomon Islands. *Pacific Science* 2:213-239.
[125] Birdlife International. 2015. Birdlife International Pacific. Available from http://www.birdlife.org/pacific (accessed October 29, 2015).
[126] Conservation International. 2015. Critical Ecosystems Partnership Fund Asia-Pacific Region. Available from http://www.cepf.net/where_we_work/regions/asia_pacific (accessed October 29, 2015).
[127] WWF Pacific. 2015. Climate Change. Available from http://www.wwfpacific.org/what_we_do/climatechange/ (accessed October 29, 2015).
[128] Secretariat of the Pacific Community (SPC). 2015. Climate Change. http://www.spc.int/en/our-work/climate-change.html (accessed October 29, 2015).
[129] Secretariat of the Pacific Regional Environment Programme (SPREP). 2015. Biodiversity and Ecosystems Management. https://www.sprep.org/ (accessed October 29, 2015).

[130] Carter E. 2007. National Biodiversity Strategies & Action Plans: Pacific Regional Review. Secretariat of the Pacific Regional Environment Programme, Apia, Samoa.

[131] Keppel G., Van Niel K.P., Wardell-Johnson G.W., Yates C.J., Byrne M., Mucina L., Schut A.G.T., Hopper S.D. and Franklin S.E. 2012. Refugia: identifying and understanding safe havens for biodiversity under climate change. *Global Ecology and Biogeography* 21: 393 404.

[132] Keppel G. and Wardell-Johnson G.W. 2012. Refugia: keys to climate change management. *Global Change Biology* 18: 2389-2391.

Appendices

Appendix 1 Threatened species in each country in the Pacific Region [9].

Oceania	Mammals	Birds	Reptiles*	Amphibians	Fishes*	Molluscs*	Other Invertebrates*	Plants*	Total*
American Samoa	1	8	6	0	10	5	59	1	**90**
Cook Islands	1	15	3	0	11	0	32	11	**73**
Fiji	6	14	14	1	13	68	97	65	**278**
French Polynesia	0	31	2	0	30	34	31	47	**175**
Guam	2	14	5	0	10	6	54	4	**95**
Kiribati	1	5	2	0	11	1	80	0	**100**
Marshall Islands	2	3	4	0	13	1	72	0	**95**
FSM	7	10	7	0	19	4	111	5	**163**
Nauru	1	2	0	0	9	0	68	0	**80**
New Caledonia	9	16	54	0	30	28	97	259	**493**
Niue	1	8	3	0	8	0	30	0	**50**
Northern Marianas	4	16	4	0	13	4	53	5	**99**
Palau	4	5	3	0	15	40	106	4	**177**
PNG	39	38	9	11	48	2	179	145	**471**
Pitcairn	1	10	0	0	9	5	11	7	**43**
Samoa	2	6	5	0	13	1	61	2	**90**
Solomon Islands	20	25	5	2	18	2	149	17	**238**
Tokelau	0	1	2	0	8	0	35	0	**46**
Tonga	2	5	4	0	12	4	43	4	**74**
Tuvalu	1	1	3	0	10	1	77	0	**93**
Vanuatu	7	9	4	0	15	4	88	10	**137**
Wallis and Futuna	0	9	2	0	11	1	64	1	**88**

*Groups that have not been completely assessed.

Appendix 2 Observed and projected changes in the climate of the Pacific region [16].

Variable	**Observed Change**	**Projected Change**
Atmospheric Temperature	Increase of 0.18 °C since 1961	Increase of 0.5 – 1.0 °C and 2.0 – 4.0 °C for 2030 and 2090, respectively, under very high emissions scenario
Rainfall	SW and NW Pacific – wetter; Central Pacific – drier over past 30 years	Increase in average annual rainfall; fewer droughts; extreme rainfall events will be more common
Sea Level	Variable across the region	Increase of 26 – 55 cm by 2081 – 2100 relative to 1986 – 2005 (RCP2.6) Increase of 45 – 82 cm (RCP8.5)
Cyclones	Decrease in total number of cyclones	Less frequent but more severe cyclones

Appendix 3 Trends in characteristics of species with climate change and severe weather listed as a threat by IUCN [9].

Species Characteristic*	**No. of Species**				
	Amphibians (3)	**Birds (196)**	**Mammals (16)**	**Reptiles (13)**	**Vascular Plants (77)**
Restricted Range (altitudinal *e.g.,* habitat in cloud montane forest; area, *e.g.,* habitat on low lying atolls) (ID)	3	119	10	11	75
Physiological processes susceptible to increasing temperatures (D)	3	119	12	11	13
Vulnerable to fires (D and ID)	2	-	1	-	55
Vulnerable to extreme weather events (cyclones, storms, typhoons, droughts) (D and ID)	-	6	12	11	6
Migratory processes impacted by increasing temperature (D and ID)	-	30	-	-	-
Reproductive processes impacted by increasing temperature and alterations to rainfall regimes (D)	3	2	-	2	-
Highly specific rainfall requirement (D and ID)	-	-	-	-	7
Dispersal limited (D)	3	-	1	11	2
Foraging behaviour associated with temperature and rainfall (D)	3	2	-	2	-
Increased susceptibility to diseases due to changes in temperature and rainfall (ID)	-	9	-	-	1
Dependent on highly specialised relationships *e.g.,* pollinators (ID)	-	-	-	-	2

*Characteristics are not exclusive. Numbers in parentheses represent total number of species within each class.

D = characteristic that increases a species' vulnerability to the direct impacts of climate change; ID = characteristic that increases a species' vulnerability to climate change indirectly.